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BRIDGE DECK RESTORATION METHODS AND PROCEDURES

PART I

REPAIRS

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16. Abstract

Problems associated with restoration of deicing salt damaged decks of highway structures are discussed. Types of restoration, methods for selecting the type, contract quantities, repair materials and repair methods are covered. In addition, galvanic corrosion and its effect on deck restoration is also discussed. It is emphasized that a restoration is a cost/benefit expediency for gaining additional deck service life.

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This report is primarily a compilation of data furnished by Engineers from the Construction, Maintenance and Specification Sections of the Bridge Department and from the Materials and Research Department; all of the California Division of Highways. It reflects experiences gained by these people during restoration of approximately 110 salt damaged bridge decks in California. Their contribution was not only essential to the writing of the report but it also added authority to it by virtue of their expertise. Other very essential contributors were the author's supervisor, G. D. Mancarti, and his assistants, R. L. Boulware and M. W. Horn. The efforts of all contributors are greatly appreciated.

BRIDGE DECK RESTORATION-METHODS AND PROCEDURES

Part I:

REPAIRS

INTRODUCTION

History

Salting to prevent icing in the mountains or frost in the valleys is causing premature bridge deck deterioration in California. When deicing salts reach the deck reinforcing steel, an electrolytic action begins which causes some steel to corrode. As the corrosive particles build up they expand against the concrete covering the steel. As the process continues, the tensile strength of the concrete is exceeded and intermittent cracks radiate out horizontally from the top mat of steel forming what is commonly referred to as an undersurface fracture. Traffic impact causes the concrete above the undersurface fracture to eventually break up and ravel out leaving a pothole in the deck surface and exposed reinforcing steel, see Figure 1. These potholes are hazardous, unsightly and costly to patch.

Bridge Deck Pothole

Figure 1

Potholing is the first visual manifestation of serious deck deterioration. Unless the deterioration is checked, the process continues until the lower mat of steel is also affected. The end result is a complete break out of the deck.

With an objective of solving the problems assoicated with deck deterioration, a Federal Highway Administration sponsored research project was begun in California during the latter part of 1969. The specific objectives of this research are:

1. To determine the most economical and effective bridge deck restoration methods for repairing deteriorated decks.

2. To develop protective systems which will inhibit continued action of deicing chemicals on restored decks.

3. To develop a tool or method of measuring deck deterioration rate.

The research has been channeled into three basic areas. They are: (1) Repair methods, (2) bridge deck seals, and (3) asphalt concrete protective overlays. Interim reports will be issued in each area as the research progresses, with a final report covering the entire project at its conclusion. This interim report covers work done thus far on repairs. The text and conclusions are based primarily on experiences gained on deck restoration projects in California.

Procedure

The normal procedure to restore a salt damaged bridge deck in California consists of removing all concrete fractured by corrosion expansive forces, cleaning the exposed steel, painting the steel and adjacent concrete with epoxy, filling the hole back to original grade with either epoxy mortar or portland cement concrete, sealing the deck with a waterproof membrane and placing a protective or hold down blanket of asphalt concrete surfacing over the entire deck.

This procedure is based on the assumption that: (1) potholing is the major problem; (2) electrochemical action is the primary source of the potholing problem; (3) chlorides have penetrated to most of the top steel mat in sufficient quantities to cause corrosion in that mat, but have not yet affected the bottom mat; (4) removal of those areas where corrosion is active will not necessarily prevent corrosion activity from beginning in other areas of the top steel; and (5) corrosion will ultimately require the deck to be replaced prematurely as compared to a deck which is not salted. Hence, the restoration procedure is an <u>economic delaying tactic</u> to gain additional life of the deck, but one which will eventually be negated by widespread corrosion activity.

An alternative to California's restoration practice of patching, sealing and overlaying is to simply patch potholes as they occur and replace the deck when the patching becomes too extensive. Arguments against this practice are: (1) a large number of patches made in a heavy freeze-thaw environment fail in less than one year, some fail just around their periphery, others fail completely; (2) a large number of potholes form during the winter months, a time when patching is very difficult; and (3) the time to deck replacement is probably shortened.

Patching the same area or just outside the periphery of previously placed patches becomes very costly. The continuous formation of potholes and the long exposure of potholes in the winter months constitute a continuous traffic hazard. In addition to being costly and hazardous, the practice of just patching potholes as they occur is undesirable due to their very unsightly appearance. See Figure 2.

Unsightly Deck Patches

Figure 2

PROBLEM

Galvanic Corrosion

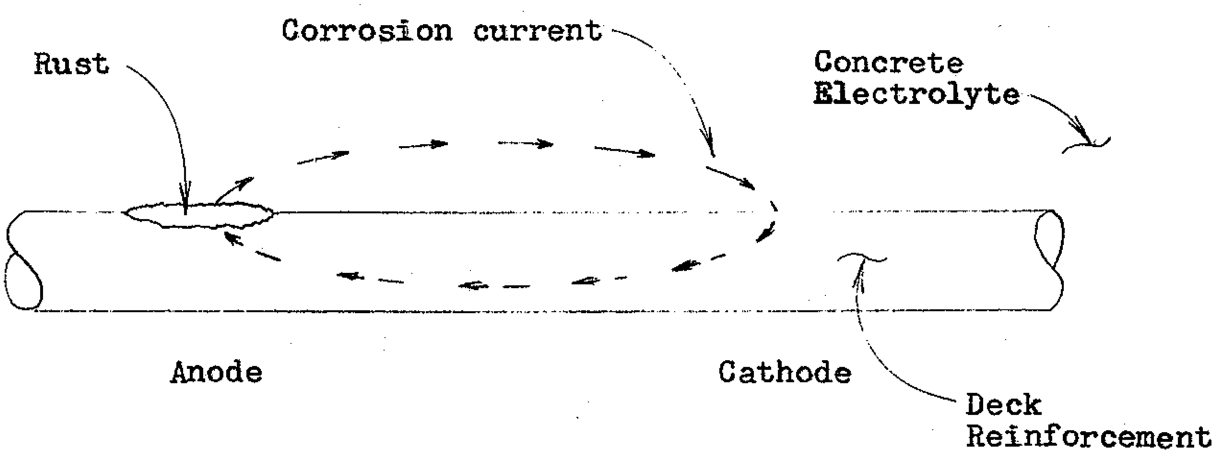
The following discussion of corrosion is purposely given in general terms. Numerous liberties are taken by generalizing rather than presenting technical details. A more theoretical discussion on corrosion can be found in many other publications(1-4). Data which substantiates that galvanic corrosion is the primary cause of deck deterioration in a deicing salt environment in California are given in a report by Boulware(5).

Corrosion is a natural process. It is simply nature's way of reverting refined metals to their nature state. For instance, the basic ingredient of reinforcing steel and corrosion deposits (rust) on steel is iron oxide. How soon this return to the natural state occurs is greatly dependent on the environment in which a metal exists.

Many factors affect the rate of steel corrosion but it usually corrodes rapidly in an acid environment and very slowly in an alkaline environment. Inasmuch as normal concrete is highly alkaline, it offers very good protection for reinforcing steel. The presence of chlorides in concrete, on the other hand, reduces its alkalinity and thereby renders it less protective. Even small amounts of chloride change the Ph characteristics of concrete, but more than a small amount is required to significantly affect its protective characteristics. It has been suggested[6] that approximately two pounds of chloride per cubic yard of concrete or 500 ppm is the minimum chloride content required to cause serious steel corrosion.

The presence of chloride not only reduces the protective properties of concrete but also aids in increasing potential differences between areas of a given reinforcing bar or between adjacent bars by being at non-uniform concentrations at the bar level.

When a metal is placed in an electrolyte -- a non-metallic electric conductor -- natural self generated galvanic corrosion activity begins if there is a potential difference between areas of that metal. The galvanic corrosion process on metal in an electrolyte, Figure 3, is the same



SIMPLIFIED SCHEMATIC OF A GALVANIC CELL

Figure 3

as the electro-chemical action which occurs in a dry cell battery as it is producing an electrical current. That is, due to potential differences between two electrodes in a battery, or between two areas of a single metal bar, a chemical process causes current to flow through the electrolyte from one electrode, or area, to the other. The circuit is completed in a battery through external physical connections and in a bar through the bar itself, or in the case where several bars are present, through physical contact of the bars.

Concrete is not a good, but is a suitable, electrolyte for galvanic corrosion. Therefore, if the other requirements for galvanic corrosion are present in reinforced concrete, corrosion activity will begin, and some areas of the steel will corrode.

In the galvanic process, the area where current leaves the metal is where corrosion occurs. This area is called the anode of the system. The area where current enters the metal does not corrode and is called the cathode of the system. The locations of the anode and cathode with respect to each other can be either very close (fraction of an inch) or very far away (several feet).

Formations of anodic and cathodic areas are not necessarily permanent, especially insofar as cathodic areas are concerned. As the corrosion process continues, various kinds of deposits can accumulate on either the anode or cathode. These deposits can greatly affect the process, even stop it under ideal conditions. (Unfortunately these ideal corrosion inhibiting conditions probably never exist in a bridge deck). Furthermore, weather, concrete porosity, continuous changes in the chloride content and other factors combine to cause a change in the potential difference between steel areas. These actions in turn cause a change in the galvanic corrosion activity. This is best illustrated by considering what happens in a bridge deck. At some point in time after the deck is constructed and deicing salts are applied, areas of it become conducive to corrosion and an anodic area is formed on the steel. All of the other steel around it at first is cathodic to it. Some time later, due to differences in potential caused by a combination of factors referred to, another steel area will become anodic to its surrounding steel. This development of other anodic areas is repeated time and time again until most of the steel area in the deck is anodic and the deck is in effect filled with numerous small, battery like, galvanic cells.

Patching Effect

Now consider what happens when an anodic area is disturbed by removal of salt laden concrete (electrolyte) from around the steel, as is done in the repair of a salt damaged bridge deck. Since the electrolyte path of the current has been removed, galvanic corrosion will cease. But when portland cement patching material is placed around the bar the electrolyte is again available and galvanic corrosion in that area can resume, unless steps are taken to preven it. (Necessary steps will be discussed later). However, as a result of the patching, conditions for supporting galvanic action have been changed. The patching material is, or at least should be, chloride free. Concrete surrounding the steel just outside the patched area usually has sufficient chlorides to cause serious corrosion. Thus, under usual conditions a greater potential difference exists between the steel in the patched area and the steel outside the patched area than it did before the original concrete was removed. Since there is a potential difference, galvanic corrosion should begin but in a different way than it had before. Inasmuch as anodic areas usually begin in areas of least electrical resistance, and chlorides reduce the resistivity of concrete, it follows that steel in the chloride free patching concrete will become cathodic to that in the surrounding concrete containing chlorides. This is reversed action to what it was before the patching was done where the steel outside the area to be patched was cathodic to that inside the area.

Generally speaking, the greater the potential difference between two areas the greater the likelihood of corrosion. In the case of the patched versus the non-patched areas, the potential difference was more than likely increased as a result of the patching. Hence, the patching could increase the chances for corrosion of the steel in non-patched areas. However, the patching effect on corrosion can be greatly diminished or completely eliminated by insulating the steel in the patched area from the electrolyte (patching material). Theoretically, if the steel is insulated, current can neither enter nor leave it from its surface; hence, it can no longer participate in the galvanic activity. (Insulation is provided in California by an epoxy coating applied to the steel just prior to placement of the patching material. It should be reported however that corrosion has subsequently been found in epoxy concrete patches in which the steel had supposedly been painted with epoxy. The reason for this has not yet been determined.)

Suppose all active anodic areas are removed from the bridge deck and the areas are patched with epoxy bonded concrete, (steel is insulated). What effect should this have on galvanic corrosion? The answer is that if the steel in the repaired area is truly insulated, it will not galvanically participate with steel outside the patched area. The steel outside the patched area, on the other hand, does not need participation of the steel inside the area for it to become active. If there is a potential difference along the steel outside the patched area, then the environment is conducive to corrosion and galvanic action will begin. Hence, in the restoration of a bridge deck, the only permanent repair is one where <u>all</u> concrete containing sufficient chlorides to cause corrosion is removed.

REPAIRS

Repair Type

To attempt a theoretically permanent repair, not including replacement, of a salt damaged bridge deck which has reached the potholing stage is impractical. In the first place, due to differences in concrete porosity, concrete cracking, variations in depth of cover, and other factors, so many areas of the deck would require sampling for salt content at the steel level that a large percent of the deck would be removed by exploration coring. This in itself would be very expensive. In the second place, with few exceptions, at the time a deck has started potholing, such a large percent of it has sufficient chlorides to cause corrosion that it would be more economical to completely remove and replace it than it would be to remove that concrete containing high chlorides and patch the remaining voids. Even though more concrete is removed in the replacement method, the removal techniques lend themselves to much higher production rates, with overall attendent lower cost, than do those in the patching method where care must be exercised to minimize fracturing adjacent concrete.

The same general economic reasoning can be applied to the argument of just removing damaged concrete rather than removing all anodic areas as a restoration practice. As stated earlier, the removal of existing anodic areas would stop galvanic action in the deck at the time of removal but soon thereafter other cells would form. This fact coupled with the expense to locate and remove anodic areas causes this practice to be unattractive. In addition, as shown by Boulware[5], locating boundaries of anodic areas is a difficult problem. It is much less expensive to remove only that concrete which has already been fractured by corrosion expansive forces and patch the void.

At this time, reliable cost/benefit ratios for the two most widely accepted restoration methods -- (1) removing all anodic areas and (2) removing just the fractured concrete areas -- cannot be made due to the subjectivity which has to be applied to the life expectancy of the method used. Thus far there are no data available on average life afforded by either method.

California's restoration practice is based on the "partial" method which requires removal of the fractured concrete only. In establishing this practice, the performance history of two decks outside a freeze-thaw area, with galvanic corrosion problems similar to those on decks within a freeze-thaw area, were used as a guide for determining the life expectancy of a partial restoration. The two decks had been constructed under previous specification allowing calcium chloride in the mix to effect rapid concrete set. After a few years, the steel in these decks corroded and caused potholes in the same manner as that which occurs when deicing chlorides are used. These potholes were patched with concrete and the decks were covered with 3" of asphalt concrete. One deck has now performed 22 years and the other one 13 years with very minimum maintenance. Investigations have shown that corrosion has continued in these decks, but the loss of steel sections have not been excessive and the blanket of AC has successfully held down the fractured concrete.

Recognizing the fact that freeze-thaw must have some effect on the performance of restoration, it was estimated that the average life expectancy of a deck restored in California would be approximately 15 years. The average life of a restoration in a valley environment where there is a minimum of freeze-thaw activity could be greater whereas it could be less in the more severe high mountainous areas. Only time will provide sufficient data for better estimating the expected life of restorations in California. The oldest deicing salt damaged restorations in California are five years old. Thus far there is no visible evidence of further deterioration; they have been maintenance free.

Some decks reach a stage of deterioration that makes the normal restoration practice on them more costly than a complete replacement, when life expectancies are taken into consideration. See Figure 4. This fact suggests that there is a transitional area where something less than the normal

Excessive Concrete Removal

Figure 4

restoration practice should be performed. As a result, California has three types of restorations. These types and when they are used are shown in Table 1. The theory behind

RESTORATION METHODS

% of Deck Area Affected by Undersurface Fractures	Type of Restoration To Be Made
Up to 30%	Remove fractured concrete, patch with epoxy bonded PCC or epoxy concrete, seal and overlay with AC. (Normal)
31 to 65%	Patch existing potholes with AC, seal and overlay with AC.
66 to 100%	Overlay with AC.

Table 1

these practices and how the limiting values were determined will be explained. It must be remembered that the figures given are based on restoration work done to date and will change as character and type of work changes.

Restoration Cost

As has been stated, it is estimated that the normal type restoration will provide approximately 15 years of further effective service life. The generally accepted anticipated effective service life of a new deck is 50 years. Therefore, the break even cost ratio of restoration to complete replacement should be proportional to the ratio of their respective life expectancies.

Since their life expectancy ratio is 15/50 a restoration should not cost more than 30% of a replacement cost.

The average cost to recently replace five bridge decks in California was $13.00 per square foot. Therefore it would be reasonable to spend for a restoration $13.00 x 0.30 or $3.90 per square foot of total deck area, or round it off to say $4.00 per square foot.

Based on the total cost of approximately three fourths of the restoration contracts in California, the approximate average percent cost for the various items of work is shown in Table 2.

Approximate Percent of Total
Cost for Various Items of Work

Traffic Control	17%
Remove concrete and patch	52%
Deck seal	14%
AC overlay	12%
Misc. (bleeders, headers, etc.)	5%
	100%

Table 2

As is shown, the removal of unsound concrete and necessary work to patch the void accounts for approximately 52% of the total cost of the contract. Therefore if a total of $4.00 per square foot is available for the restoration then $4.00 x 0.52 or $2.08 per square foot is available for removal of the fractured concrete and patching the remaining void.

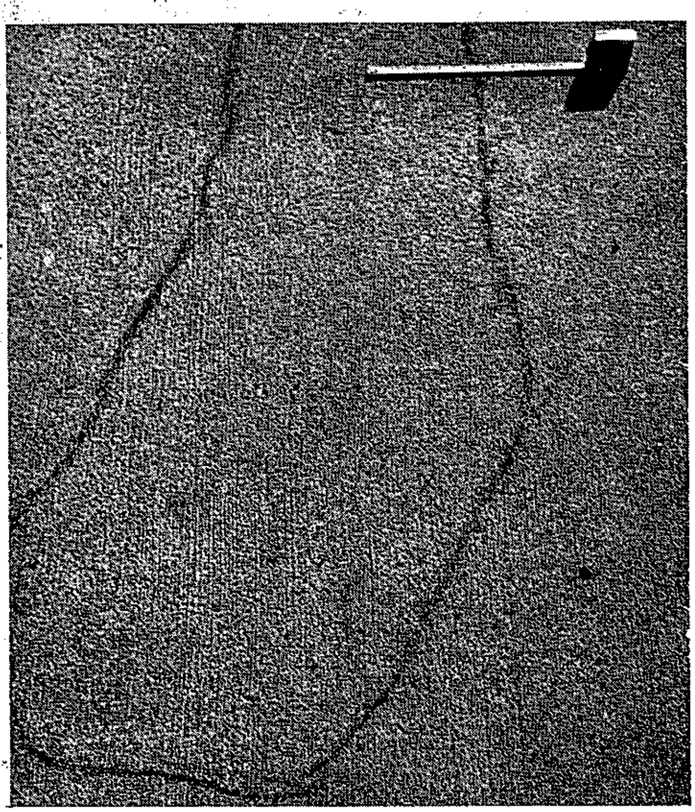
The average bid price to remove and patch on the contracts was $7.50 per square foot of area removed. Therefore the percent of deck which can be patched without exceeding the $2.08 average cost of the entire deck is 2.08/7.50 or 27%. (California has rounded this figure to 30%).

Thus we have that whenever fractured concrete exceeds approximately 27% of the entire deck area, the normal restoration is economically unsound. On the other hand, a replacement at this time is not necessarily economically sound since from a structural standpoint the deck still has several years of service life; only its riding quality, due to potholes, is seriously affected. Consequently, some form of temporary repair should be done so as to obtain this additional useful life.

A decision as to the extent of restoration to be performed when the total affected area is greater than 27% is greatly affected by the same subjective rationale as is the normal restoration. Since there are no data available to be used as a guideline, the two other alternative restoration methods and the limiting values when they are to be used were arbitrarily selected.

Locating Fracture Boundaries

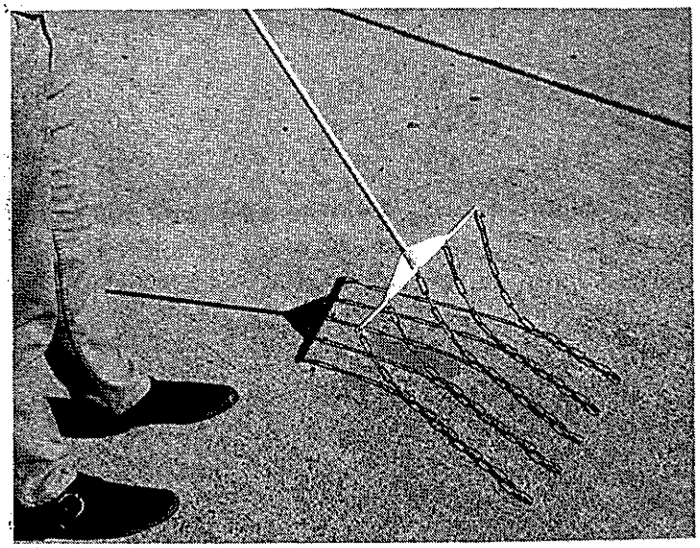
Most decks needing restoration have begun to pothole due to fractured concrete raveling out under traffic. It is not unusual however to find large areas of undersurface fracture without any evidence of this incipient pothole on the surface, as is shown in Figure 5. Some type of sounding device, such as a hammer, rod, or chain, is needed to locate these fractured areas so as to repair them. By pounding the surface with the device, or by dragging the device over the surface, and observing the sound, a fractured area is easily discerned by the low pitched "hollow" sound which results when the operation is directly over it.



Outline of Undersurface Fractured Area

Figure 5

The broom shaped chain drag shown in Figure 6 has proven to be a very effective sounding device. Its greatest



Chain Drag for Detecting Undersurface Fractures

Figure 6

attribute is that large areas can be rapidly covered with a sweeping motion. As an added feature, this device will detect undersurface fractures which cannot be detected by striking the surface with a hammer or rod.

Contract Quantities

If the restoration work is to be done by contract, pay item quantities must be established. Since the quantities of some of the major items, such as bonding agent and patching, are predicated on the quantity of concrete removal, establishment of accurate pay item quantities becomes difficult due to the difficulty of predicting the amount of concrete to be removed. There are three primary problems associated with predicting concrete removal quantities. They are:

1. The time differential between the deck survey for the purpose of setting up the restoration contract and when the actual restoration begins. (Usually it is long enough to permit corrosion to spread to other areas and cause additional undersurface fractures.)

2. Variability of concrete cover over the reinforcing steel in various areas of the deck.

3. Removing additional concrete due to finding light corrosion on the steel during concrete removal operations. (Even though it has not caused an undersurface fracture.)

Some control is possible on all three problem areas.

There is a logistic time delay in setting up the restoration contract due to such things as printing the special provisions, advertising, etc., which cannot be prevented. Therefore, to minimize the time between making the field survey needed to establish the concrete removal quantities and the actual removal work, a final field survey should be made just prior to printing the special provisions. Any changes in quantities found by this survey should be made in the final special provisions.

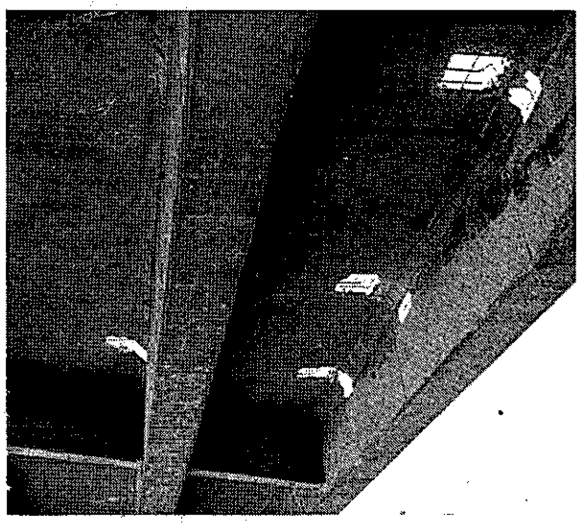
The depth of anticipated concrete removal can be more accurately predicted if the concrete cover over the steel is determined. In pot-holed areas the steel is usually exposed and the cover is easily determined. In undersurface fracture areas it can be closely approximated with the aid of a pachometer.

When considering whether or not to trace out corrosion on reinforcing steel which has not progressed to the state of causing undersurface fractures, one should keep in mind the overall restoration problem. The restoration practice should be designed to obtain the best cost/benefit ratio. Or more descriptively stated it should provide the greatest extension of deck life at the least cost. The most expensive operation in a restoration contract is concrete removal and patching. Hence, this operation should be held to that which is considered economically justifiable. As stated elsewhere in this report, corrosion will continue in the deck after the restoration work is completed. This corrosion will cause additional undersurface fractures. Information is not yet available to predict when this will occur. But since it will occur eventually, one should not be overly aggressive in removing and patching in areas of sound concrete, even if there is evidence of corrosion on the steel. Where to draw the line, when to remove and when not to remove, has to be a subjective decision. If the steel is badly corroded it will probably soon cause an undersurface fracture; hence, the concrete around it should be removed. If it has light corrosion it is probably no different than the corrosion on steel in other anodic areas which has not yet caused undersurface fracturing and therefore will not be repaired; hence, concrete around light corrosion should not be removed. If tracing of corrosion in sound concrete is held to a minimum, the final concrete removal quantities can be estimated with a much higher degree of accuracy.

In addition to the three primary problems causing difficulty in predicting the quantity of concrete removal, there are also two lesser problems. They are: 1) Moisture content of the deck at the time of chaining and 2) the volume of concrete which will be removed beyond the undersurface fracture area.

If the chaining is done soon after a rain or whenever the moisture content of the concrete is very high, some undersurface fractures will be filled with water and will therefore not produce the normal "hollow" sound as a chain passes over them. This has not been a serious problem but has been blamed for differences in results of chainings made within a short time span.

There is a wide variation in the skill of jackhammer operators found on restoration projects. This has been demonstrated on several occasions when holes were punched through the deck at the start of a contract with virtually none towards the end after the operators became more experienced with the work. See Figure 7. The quantity of



Holes Jackhammered Through the Deck

Figure 7

additional concrete which will be removed in the vertical direction is extremely difficult to predict. On the other hand, it has been found that in the horizontal direction the average additional quantity which will be removed can be calculated by including approximately 6" outside the area of discernible undersurface fractures.

Removing Concrete

The size of jackhammer to be used in removing fractured concrete during restoration is to some extent dependent upon the skill of the operator. Experience has shown however that the maximum size should be no more than 65 pounds for the initial breakout, regardless of the operator's skill. For less skilled operators the maximum should be 30 pounds. Final clean up of small areas which were fractured by the larger jackhammers should be removed with a small air powered chipping gun. See Figure 8. Or if preferred, the final

Initial Breakout With a Jackhammer -
Finishing With a Chipping Gun

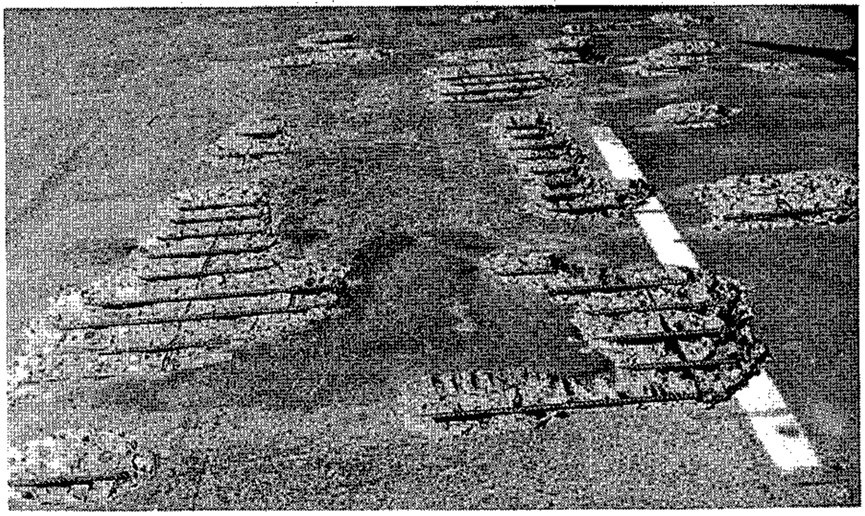
Figure 8

clean up can be done with a small handpick, such as a geologists pick.

The small fractured areas are best found by "tinkling" a single chain over the surface. Each area which has been worked on should be checked with the single chain after each chipping operation to ensure that all significant undersurface fractures have been removed.

It is common practice to provide 1/2" minimum depth vertical edges on concrete before it is patched to prevent the edges of the patch from ravelling. This is often obtained by saw cutting. Special effort to obtain a vertical edge is not necessary in restoration patching because 1) the normal chipping operation usually causes a surface which is sufficiently vertical or it can be easily obtained by a chipping gun and 2) since the patch will be protected from direct wheel contact by an asphalt concrete overlay it will not be as susceptible to spalling as is a patch which is not protected.

In fractured areas, the concrete should be removed 1" below the steel which is corroded. The primary purpose of this depth is to facilitate painting the reinforcing steel with epoxy. See Figure 9.



Undersurface Fractured Areas
Prepared for Patching

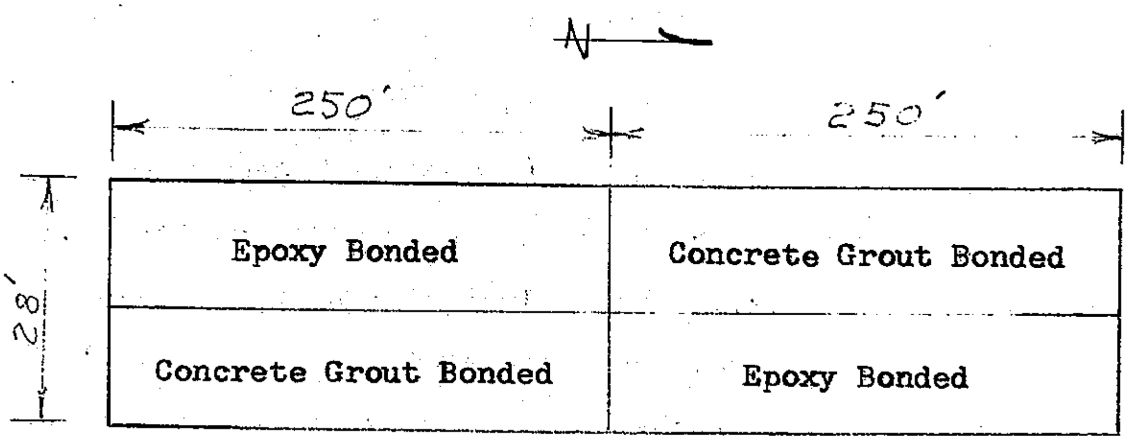
Figure 9

Bonding

It is general practice to provide a bonding agent when making thin patches. The most common agents used are neat coment grout and epoxy. When selecting the type of agent to be used in a salt damaged restoration, not only should the adhesive ability of the agent be considered but its electrical insulating properties must also be taken into account.

As stated earlier, galvanic corrosion begins whenever a potential difference of a certain magnitude develops along the reinforcing steel. Whenever a portion of salt contaminated concrete is replaced with salt free material, theoretically a high potential difference results between the replacing material and the surrounding concrete and this causes an acceleration of steel corrosion in the remaining salt contaminated concrete. Again theoretically, the effect of this potential difference can be greatly diminished or completely eliminated by coating the reinforcing steel in the patched area with an electrical insulating material.

For the purpose of verifying the theoretical concepts under field conditions, a 500-foot long bridge was patched with both cement grout and epoxy bonding agent. The two materials were used in opposite quadrants as shown in Figure 10. The

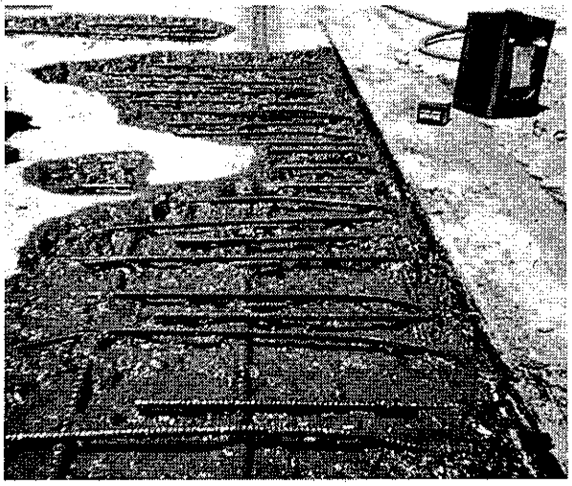


Layout of Bonding Materials
Used on Kings River Bridge

Figure 10

testing period has not been long enough to draw final conclusions at this time, but by electrical potential and chain drag measurements the areas where cement grout bonding agent was used have developed appreciably more anodic activity and undersurface fractures than have the areas where epoxy bonding was used.

The use of epoxy bonding material in California has not precluded steel in the patched area from participating in the galvanic corrosion process. The magnitude of active corrosion in patched areas of deck restoration has not been determined, hence it is not known if the few cases where corrosion has been found are unique or typical conditions. Since under lab conditions the epoxy used appears to be a good electrical insulator, it is conceivable that during field application the epoxy at times has been either improperly mixed or improperly placed. More work directed towards investigating this phenomena is planned. In the meantime California will continue to use only epoxy as a bonding agent in restoration work. See Figure 11.



Epoxy Bonding Material
Applied to Area to be Patched

Figure 11

An epoxy bond coat can be either sprayed or brushed in place. Generally, when sprayed, a follow-up brushing is necessary to preclude holidays on both the concrete and steel, especially the underneath portion of steel, and excessive build-up in low spots of the concrete. See Figure 12. A distinct

Spray Applied Epoxy Bond Coat - Smoothed By Brush

Figure 12

advantage of spraying when in-the-head mixing equipment is used is that the entire pot life of the epoxy occurs while it is on the deck. Since the material to be bonded has to be placed while the bonding material is still tacky, the longer the pot life of the bonding material when it is placed the longer the safe placing time of the other material.

Materials

Two types of patching materials are used in California. They are portland cement concrete and epoxy concrete. The type selected for a given job depends on either placing or traffic conditions. PCC is the favored material due to its lower cost. The use of epoxy concrete is reserved for special cases such as when overnight traffic lane closures are undesirable and when only small quantities are required.

A PCC mix normally used contains 9 sacks of cement per cubic yard and 3/8 or 3/4 inch maximum size aggregate. Patches made with this mix are usually cured for 36 hours before they are exposed to traffic. If five days of cure time are available a 7 sack mix is usually used.

Air is not purposely introduced into PCC patching material because 1) the mixing and placing conditions are not conducive for controlling air content and 2) inasmuch as the deck will be sealed, salt, which acts as a catalyst in the scaling process of concrete, will be prevented from coming in contact with the patching material; hence, the resistance to concrete scaling afforded by air entrainment is not necessary. I don't agree DLL

The most significant requirements for epoxy concrete in a freeze-thaw environment are: 1) its thermal coefficient of expansion must be similar to that of concrete or it must be very flexible, and 2) it must contain a minimum of voids.

When epoxy mixes which have substantially different thermal coefficients of expansion than PCC are placed in thicknesses greater than about 1/4 inch in a severe freeze-thaw environment, a large change in temperature will cause different strains in the two materials. PCC usually being the weaker of the two will shear at its interface with the epoxy. The problem is eliminated by a more equal thermal coefficient of expansion or a highly flexible epoxy system which will absorb the strains as they occur.

Excessive voids in an epoxy concrete can lead to internal destruction by freezing of water entrapped in the voids. A volume ratio of approximately 4 to 1 of uniformly graded sand-aggregate to epoxy Sometimes usually produces an epoxy concrete mixture that is sufficiently rich to preclude harmful voids. The same criteria for determining the maximum size aggregate in a PCC mix should also be used in an epoxy mix.

Most epoxies are moisture sensitive during curing; therefore, the sand and aggregate must be at least surface dry before they are used with these epoxies.

Mixing

Portland cement concrete is mixed either by hand, small on-site mixer, transit mixer, pug mill or a mobile, continuous mixer. All except the mobile mixer are common to construction and maintenance practices so they will not be discussed. The mobile, continuous mixer, however, is fairly new and since it does introduce some problems on restoration jobs it will be discussed. Figure 13 shows the mobile mixer.

Concrete Mobile -- A Self-Contained
Concrete Mixer

Figure 13

The mobile, continuous mixer is a self-contained mixer as it carries all ingredients necessary for supplying mixed concrete at the job site. During mixing operations, materials are fed by belt to an auger type shaft which mixes them into a concrete mass as it moves them towards the discharge end. The cement is fed at a fixed rate onto the feeder belt. The richness of the mix is therefore controlled by controlling the rate of aggregate fed to the belt. The equipment is designed for mixes in the range between 5 to 6 sacks of cement per cubic yard. It therefore does not operate with smooth efficiency when programmed to produce a substantially richer nine sack mix.

Mixing time in the auger is only 12-15 seconds. **This short** a mixing time frequently results in a false set or a premature stiffening of the discharged concrete, thereby making it difficult to place and finish. The normal tendency is to overcome this problem by adding more water. This does not accomplish the objective as false set continues to occur. The only accomplishment is an overly wet mix which results in poor compressive strength and excessive shrinkage cracking. The proper method of correcting false set is by vibration or working the mix. Hence, if false set becomes a problem during patching, the mix should be thoroughly worked or vibrated before it is placed and finished.

Epoxy concrete is usually mixed by hand in a mortar box (Figure 14) or mechanically in a pug mill. In either case

Hand Mixing Epoxy Concrete
in A Mortar Box

Figure 14

there is a tendency to under mix the ingredients and thereby produce a final product which is overrich in some areas and lean in others.

Patching

Patching potholes in a deck on which vehicular traffic is causing vibrations and bending moments is not necessarily good practice, but from the standpoint of economics must be tolerated during deck restoration projects.

Vibrations are probably not too detrimental as long as there is no differential movement between the base concrete and reinforcing steel or formwork in cases where forms are used to support the patching material. If there is differential movement, it could cause a void around the steel, especially if the movement occurs after the concrete is set but is still not strong enough to resist displacement by the steel. To preclude, or at least minimize, vibration type damage, the steel should be securely tied together and it and any formwork securely anchored to the base concrete.

As traffic passes over a deck-girder type bridge the top surface of the deck is subjected to bending moments which cause both compressive and tensile stresses. When the traffic is allowed to pass within a few feet of the patching (which is necessary on most restoration projects) these compressive and tensile stresses could become very large. Compression stresses in the patched areas should not be detrimental because the concrete should remain sufficiently plastic or have sufficient strength to withstand the resulting strains. Since concrete at no time has high tensile properties, tensile stresses should cause cracking in the freshly placed patch before it gains sufficient resistance strength.

Shrinkage of the patching material also causes cracking. In fact, shrinkage rather than vibration or bending moments appears to be the greatest cause of cracking in patching materials. This assumption is based on the type and orientation of cracks observed during deck restorations.

Internal vibration of epoxy concrete is virtually impossible. It should therefore be placed in lifts not to exceed about two inches and tamped with a wooden or iron rod. The blunt end of a 1" x 2" wood survey stake is well suited for this purpose. Material in the first lift should be worked around and under the reinforcing steel, by hand if necessary.

The type of surfacing texture needed on either PCC or epoxy concrete patches depends on whether traffic will be directly on the patch or if an overlay will separate them.

If traffic will be directly on it, the patch will need normal texturing. The normal methods used to acquire texturing on PCC bridge deck placements will provide the necessary texturing on PCC patches. For epoxy concrete it can be achieved by broadcasting aggregate onto the surface as the epoxy hardens. Good texturing can be obtained on an epoxy patch with any aggregate passing sieve sizes from No. 30 to No. 8.

Surfaces of PCC patches to be overlain with asphalt concrete do not need special texturing. Those of epoxy with good richness, however, are usually slick and AC will not adhere to them. These surfaces therefore have to be provided with roughness to accommodate the AC. No. 8 or No. 4 size aggregate provides good bonding roughness.

<u>Curing</u>

Portland cement concrete is cured by spraying the surface with chlorinated rubber as soon as the sheen has disappeared. Nine sack mixes are cured for 36 hours and seven sack for five days before traffic is allowed to run over the patched area.

Epoxy concrete does not receive any special cure treatment. Traffic is allowed on the patched area when the epoxy has set sufficiently to preclude it from being marked with tire prints.

<u>Post Restoration Investigations</u>

A blanket of asphalt concrete over a restoration is essential to protect the waterproofing membrane and to hold in place concrete fractured by future steel corrosion. It is to some extent, however, a detriment insofar as monitoring future deterioration in the deck in that it hides the deck surface from view. On the other hand this fact should not be of great concern because there are two conditions which should develop before the deck becomes endangered. These are: (1) the soffit should start deteriorating (manifested by serious cracking, which causes separation of the deck into small segments; articulation between these segments; plus extensive salt leaching and water stains) and (2) the AC surfacing should segment and fail over any seriously affected area. Either condition would be a warning that repair, supplemental supports or replacement of that portion of deck is imminent. All of these conditions have occured in California; yet, there has not been a complete deck failure. Therefore, using these criteria as warnings for preventive action should be a safe, conservative practice.

All deck restorations in California are given a special annual investigation. The investigator records -- written and photographically -- all unusual conditions. It is anticipated that as experience is gained by this method the anticipated life of a restoration can be more closely predicted and repairs or replacement can be more judiciously programmed.

CONCLUSIONS

1. Salt used to prevent icing in the mountains and frost in the valleys is causing premature bridge deck deterioration.

2. Potholing of the concrete, resulting from corroding reinforcing steel, is the major type of bridge deck deterioration.

3. The corrosion process is the natural electrical-chemical, or galvanic, type caused by differences in electrical potential along a metal in an electrolyte.

4. Based on a cost/benefit comparison, it appears that three methods of restoration, depending on the extent of concrete damage, should be practiced. They are:

% of Deck With Undersurface Fractures	Type of Restoration
0 - 30	Remove fractured concrete, patch with either PCC or epoxy concrete, seal and overlay with asphalt concrete. (Normal)
31 - 65	Patch potholes with asphalt concrete, seal and overlay with asphalt concrete.
66 - 100	Overlay with asphalt concrete.

5. Predicting concrete removal for contract quantity estimate is complicated by: a) Time delay between the last field survey before the special provisions are written and the work begins, a) variability of concrete cover over the reinforcing steel and c) tracing out light corrosion on steel which has not caused fractures in the concrete.

6. Shrinkage is a greater contributor to cracking in portland cement concrete patching placed on a deck while traffic is passing over the deck adjacent to the patch than is either vibration or moments induced by the traffic.

Not so!

7. Air entrainment is not necessary for PCC patching which will be protected with a waterproof membrane.

8. Epoxy concrete placed in a severe freeze-thaw environment must **a)** have a thermal coefficient of expansion similar to concrete or be very flexible and b) have a minimum of potential water storing voids.

9. The continuous type concrete mobile mixers cause false set or premature stiffening of the discharged concrete. Addition of more water will not prevent false set; vibrating or working the mix will.

10. California's restoration practice is based on the assumption that a) active corrosion in a chloride damaged bridge deck can be stopped only by the removal of all concrete containing as much as 500 ppm chloride ion; b) removal of <u>all</u>

active anodic areas would buy additional life of the deck but at too great an expense; c) removal of all fractured concrete areas, patching, sealing the deck with a waterproof membrane and placing a protective hold-down blanket of asphalt concrete buys sufficient additional life of the deck to yield the lowest cost/benefit ratio.

RECOMMENDATIONS

1. Design and execute restorations of salt damaged bridge decks on the assumption that galvanic corrosion will continue and that the restoration is a delaying tactic to ultimate replacement.

2. Gather cost and performance history data on restorations and replacements for the purpose of refining restoration practices.

IMPLEMENTATION

Due to the close cooperation between various units responsible for researching, designing and performing bridge deck restoration in California, any indications that changes are warranted in the methods used are immediately implemented.

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